

Research Article

Influence of Different Diameter Ratio of Delta-ring on Sealing Performance of Ultra High Pressure Vessel for Food Processing

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Abstract: The sealing performance of sealing structure in Ultra High Pressure Vessel (UHPV) for food processing is important for UHPV to work safely. The aim of this study is to analyze influence of different diameter ratio of delta-ring on sealing performance. The FEAs models of the sealing structure were established firstly. Then, the stress distribution nephograms of delta-ring were obtained under different diameter ratio. The diameter ratio of delta-ring had bigger influence on maximal stress of top cover and cylinder. Its better value was range from 1 to 1.1 by analysis.

Keywords: Delta-ring, food processing, seal structure, ultra high pressure vessel

INTRODUCTION

Ultra high pressure vessel has many characters during processing food under ultra-high-pressure condition, such as higher operation pressure (up to 1000 Mpa), repetition loads, pulsatile pressure and temperature and so on Torrecilla *et al.* (2005) and Li *et al.* (2013a, 2013b). It is very difficult to design a perfect seal structure to solve problems caused by characters of UHPV processing. Therefore, a high quality seal structure is critical to the success of the UHPV and also is one of key problems in the design of the UHPV. The UHPV whether or not correct running as usual depends on rationality and reliability and good performance of seals. This seal structure should be easy-to-actuating, frequently actuating, sealing reliability and convenient for maintenance. If we couldn't make sure safe running of seal structure of the UHPV, it is very dangerous and wasteful for leakage of pressure transmitting medium to lead to stop processing and harmful to humans. Therefore, it is of great significance to investigate a novel seal structure for the UHPV.

The seal structure employed in this study is consisted of a gasket, an o-ring and a delta-ring with characters of simply structure, higher adaptability and good self-energizing. It is widely used in the UHPV. Although there are many numerical analysis on seal structures used in UHPV, such as O-ring and double cone seal, rarely researchers have tried to find out more about how to design high-performance seals by studying the conditions in the contact between a delta-ring and metal cylinder (Chen *et al.*, 2011, 2007; Su

and Chen, 2010). The challenge is that seals are hard to study *in situ*. The sealing capability is very complex as it is influenced by seals and counterface material, surface roughness, geometry and running conditions and so on. The lack of knowledge is partly due to the problems of observing and measurement of delta-ring stress distributions, deformations and contact area. Only Ma (2006) studied the mechanical analysis on sealing process of the delta-ring in the UHPV employed in seafood processing. In their analysis, two simplified mechanical model, that is, rectangular ring model and line model, were proposed. Based on elastic-plastic theory and principle of sealing process of the delta-ring, the contact pressure between the delta-ring and vessel shell, as well as the stress and the strain of the delta-ring were analyzed and the formulation of the residual contact pressure vs. the working pressure, the material properties and geometric parameters were obtained. The formulation can be applied to the delta back-up ring. But they didn't consider affects of the contact stress and radial clearance between inside of delta-ring and cylindrical surface of top cover. The GB150 (China National Standard) pressure vessel code does not provide specific design procedure for the seal design. The current practice is to use the semi-empirical method to design the seal structure.

In a summary, a more accurate analysis should be set up in order to gain exact stresses and deformations distribution for the delta-ring. The aim of this study was to explore a digital simulation method that makes it possible to study the stress and deformation of the delta-ring. The finite element method had been applied in UHPV to obtain the distribution nephogram of the

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stresses on the contact surface for validating the effectiveness of the sealed structure and obtaining the suitable parameters of delta-ring.

MATERIALS AND METHODS

Sealing structure of the delta-ring: A two-layer shrink-fit ultra high pressure vessel (WHGR 600-10×64) for food processing was used in this study. The maximum internal pressure was 600 MPa. The UHPV was of 100 mm in inner diameter, as shown in Fig. 1. When the UHPV worked, internal medium pressure transferred to the delta-ring by O-ring. It made the delta-ring elastic-plastic deformed to contact tightly with top cover and cylinder for obtaining excellent sealing performance. The sealing structure was composed of a cylinder, a top cover, an o-ring and a gasket, as shown in Fig. 2. The delta-ring achieved self-energizing seal by enough sealing specific pressure on its cone section. In addition, the gap between the outside of the delta-ring and inside of the cylinder disappeared by the radical shrinkage of the delta-ring to prevent o-ring pushing in. So internal pressure was higher, the sealing performance was more reliable. In order to make sure correct running of the UHPV and reveal its mechanical performance and stress distribution, it was critical to numerical simulation on the contact area among the delta-ring and the cylinder and the top cover.

Finite element analysis of delta-ring:

Mechanical performance of material: Material of delta-ring was bilinear follow-up material model. Other materials of sealing structure were a kind of line elasticity material. Their main mechanical performances of various materials were shown in Table 1.

Finite element analysis model: The finite element method was applied to obtain the contact stress of the delta-ring undergo ultra high pressure condition. The area of contact was mainly determined by the size and shape of the delta-ring that was prepared for the seal. The contact area may also depend on friction forces in

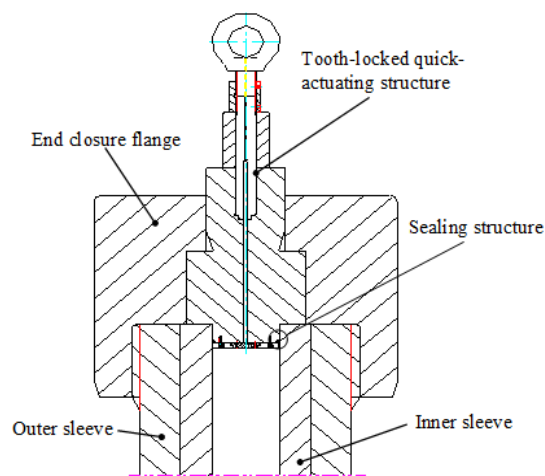


Fig. 1: Sealing structure diagram of UHPV

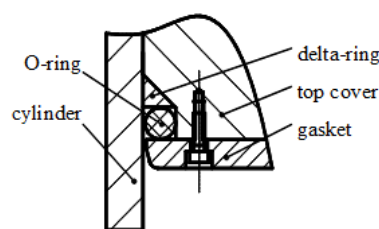


Fig. 2: Sealing structure of the delta-ring

the interface. Hence, studies of seal contacts were critical to achieve a good performance of UHPV. Finite element analysis model of seal structure was established when the internal medium pressure was 600 Mpa and top intersection angle of delta-ring was 45°. Different internal diameter of delta-ring were selected to analyze influence of different diameter ratio on sealing performance. The basic size of delta-ring and other components of sealing structure were shown in Table 2 and 3. The 2-D axisymmetric model of sealing structure was built, as shown in Fig. 3.

It was necessary to set up interfaces, there were existed in flange, top cover, cylinder and so on. The

Table 1: Mechanical performance of components of sealing structure UHPV

Components	Material	$\sigma_{0.2}$ /Mpa	E/Gpa	Poisson's ration	Density kg/m ³
Top cover	0Cr17Ni4Cu4Nb	1275	213	0.27	7780
Delta-ring	Aluminum ronze	250	103	0.33	7500
Flange	0Cr17Ni4Cu4Nb	1275	213	0.27	7780
Cylinder	0Cr17Ni4Cu4Nb	1275	213	0.27	7780

Table 2: Basic size of delta-ring

Outer diameter/mm	Inner diameter/mm	Height/mm	Top intersection angle/degree
100	90, 80, 70, 60	5	45

Table 3: Basic size of other components of sealing structure

Components	Outer or Inner diameter/mm	Thickness or Height/mm
Top cover	180/100	320
Flange	460/120	365
Cylinder	320/100	500

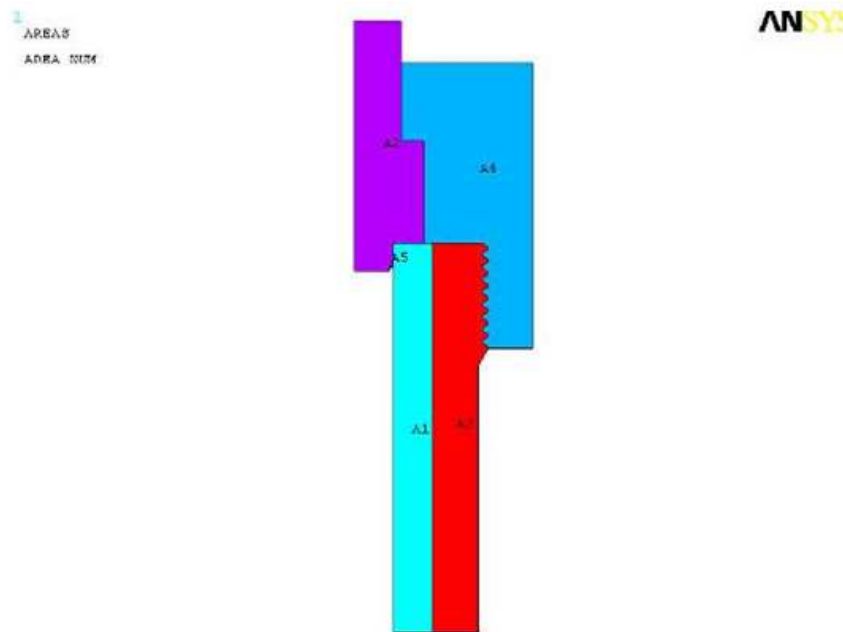


Fig. 3: 2-D model of sealing structure

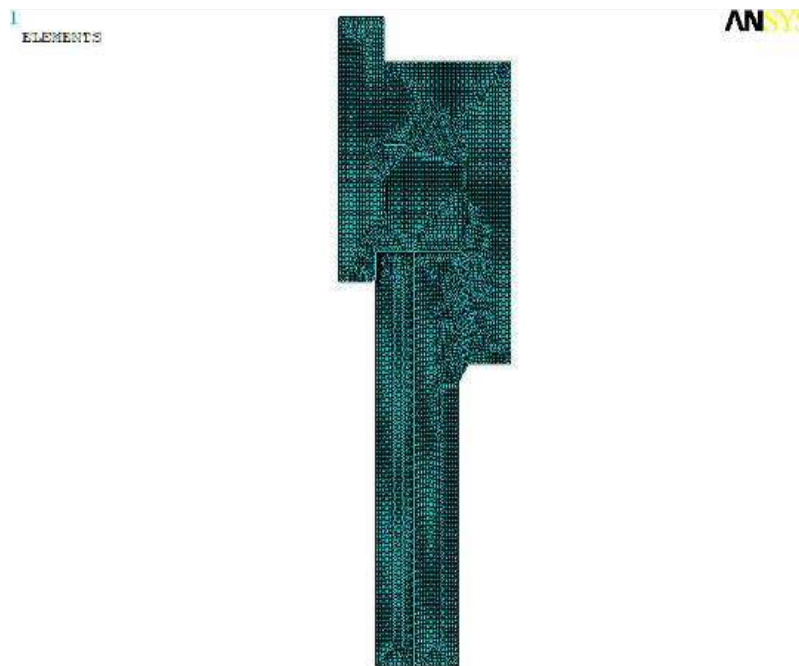


Fig. 4: Meshed model of sealing structure

seal structure model was meshed by PLANE183 cell. The delta-ring was meshed by 0.4 mm, whereas other components were meshed by 4 mm. The finite element model was meshed by the method of free mesh. Above all, the focus contact area between delta-ring and its surrounding contact area was dealt with more gridding. The total cells of meshed model were 19618, with 41630 nodes. The meshed model was shown in Fig. 4. In addition, it was supposed that the delta-ring contacts well between the cylinder and the top cover. The above

contact belonged to face to face contact. Therefore, the 2-D face to face contact model was provided by ANSYS12.0, that is, interface element CONTACT172. The CONTACT 172 was matched with TARGE 169. Then, four contact pairs were established by CONTACT172 and TARGE 169, that is, end cylinder and delta-ring, top cover and the top of flange, top cover and the end of flange, top cover and delta-ring. Simultaneity, friction angle on the cone section of delta-ring should be selected by GB150 design handbook in

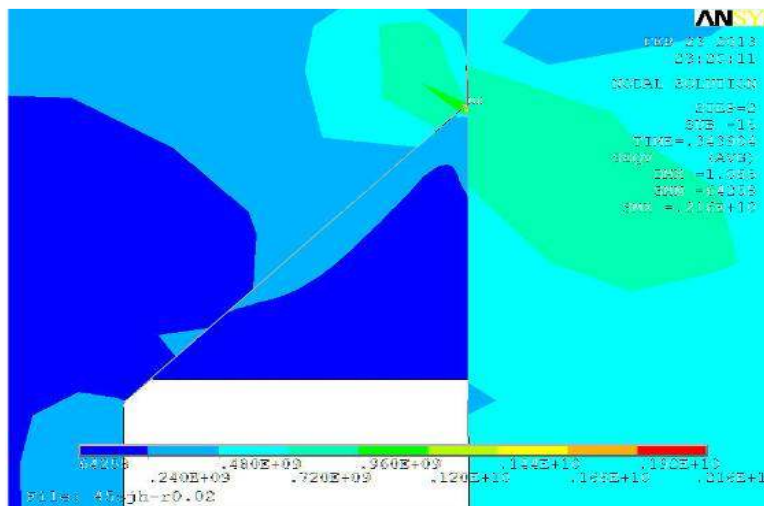
China. Based on contact material of copper and steel and its angle was 15°. The dissymmetry contact algorithm was adopted and standard single contact with the direction of normal was carried out by face-face contact model.

Boundary and loads conditions: Owing to edge stress was generated on connecting zone of end cylinder and cylinder of discontinuous structure in UHPV. If distance away from discontinuous structure is larger than $2.5\sqrt{R\delta}$, the affection of edge stress on the delta-ring stress distribution can be ignored, Where R denoted average radius of cylinder, δ denoted effective thickness of cylinder. So the length of cylinder was 500 mm by calculation. It was critical to maintain the boundary constrained condition in anlysis. To prevent move of model by axes direction, axial displacements of all notes on the end surface of cylinder were zero and upper of cylinder was freedom. The circumferential

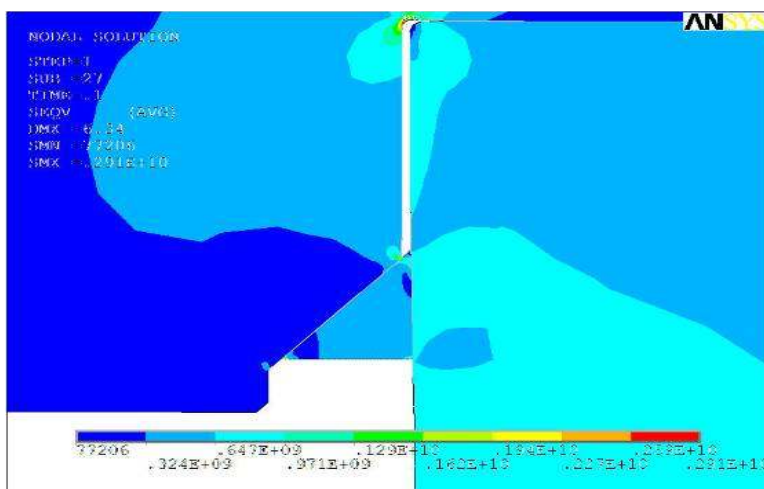
displacements of model were zero based on characters of symmetry of model and loads and deformation. Beside axial displacement, all freedoms of motion on the axes were zero. The boundary condition of pressure was that inner surface of cylinder was subjected to evenly distributed pressure.

RESULTS AND DISCUSSION

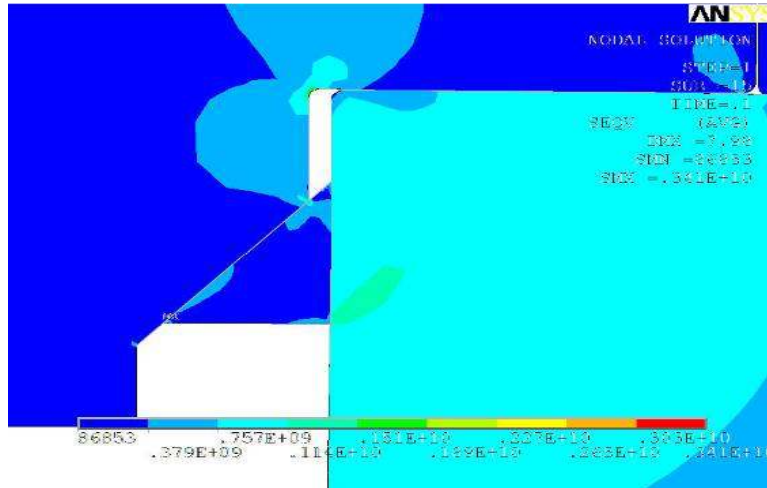
The FEAs of four different diameter ratio were performed in this study. The size parameters of delta-ring as shown in Table 2. The mises stress distribution of delta-ring were ontained, as shown in Fig. 5. With increasement of diameter ratio, the influence of delta-ring on top cover and cylinder was more obvious. When diameter ratio was bigger than 1.1, the mises stresses of top cover and cylinder were exceeded yield strength. It is easy to lead to fatigue damage for top cover and cylinder. So, the better daimeter ratio was range from 1 to 1.1.



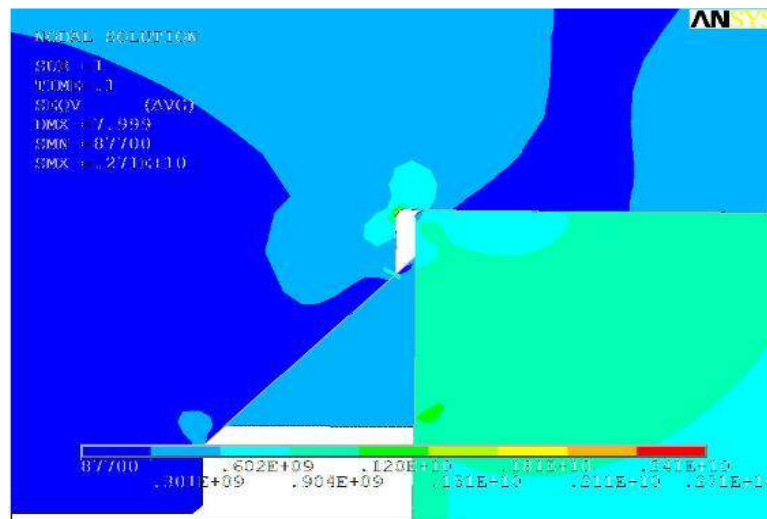
(a) Diameter ratio 1.1



(b) Diameter ratio 1.25



(c) Diameter ratio 1.43



(d) Diameter ratio 1.67

Fig. 5: Mises stress of delta-ring on different diameter ratio, respectively

CONCLUSION

The finite element analyses were performed by ANSYS12.0 to obtain influence of different diameter ratio on sealing performance. The distribution nephograms of the stress of delta-ring were obtained when diameter ratio was 1.1, 1.25, 1.43 and 1.67, respectively. The diameter ratio of delta-ring had bigger influence on maximal stress of top cover and cylinder. When its value was bigger, the mises stress of top cover and cylinder were bigger, even exceeding their yield strength. So its value was better from 1 to 1.1.

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